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DEPARTMENT OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

36-545 MIT, CAMBRIDGE, MASSACHUSETTS 02139-4307

EX PARTE OR LATE FILED

William F. Schreiber
Professor of Electrical Engineering
Emeritus



9 May 1996

Hon. Reed E. Hundt, Chairman
Federal Communications Commission
1919 M. St.
Washington DC 20554

**THE POLAROID PROGRESSIVE-SCAN HDTV CAMERA:**
*Implications for the digital broadcasting standard*

MM Docket 87-268

Dear Mr. Chairman:

On March 11, I wrote to you about the importance of not including an interlaced format in the digital broadcasting standard due to be issued. Since then, a progressive-scan HDTV camera has been shown by Polaroid at the NAB Convention, where it won the "Editors' Pick-of-the-Show" award. Further demonstrations are being given in Cambridge. This camera, developed in the USA, in part with funds from ARPA, fully meets all the requirements for the 720x1280 Grand Alliance format. It has full resolution together with very high sensitivity and signal-to-noise ratio.

The unique feature of this camera is the photosensitive CCD chip, developed by Polaroid. The chip has been placed in a modified Philips/BTS camera. It is a production-quality camera, not a prototype. As such, it is ready for delivery. Polaroid has indicated its intention of selling the camera at prices slightly below that of the interlaced HDTV cameras now available from Japanese and European manufacturers.

The importance of this camera cannot be overstated. Many of those pushing an interlaced HDTV standard have said that a full-quality progressive-scan camera was impossible to build at present, and that we therefore must include an interlaced format in the coming standard. I pointed out in my previous communication that, if we permit interlaced transmission, we shall probably never be able to make the transition to progressive scan, with its higher spectrum efficiency, superior rendition of detail and motion, easier transcoding to other formats, and enhanced computer-friendliness.

*The last remaining argument for including an interlaced format in digital television has now been removed. I urge you and the other Commission members, in setting the new broadcasting standard, to include only progressive transmission formats.*



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My opinion is that, if the Polaroid camera had been available for the ATTC tests, either the AT&T/Zenith system or the MIT/GI system, both of which used 720x1280 progressive, would easily have won the competition. In that case, the possibility of using the archaic interlace scheme in the US ATV standard would never have arisen.

Very truly yours,

William F. Schreiber

Cc:
Commr. James H. Quello
Commr. Andrew C. Barrett
Commr. Rachelle B. Chong
Commr. Susan Ness
Hon. Edward J. Markey
Mr. Richard K. Wiley
Mr. Larry Irving
Dr. Robert Pepper, FCC
Other interested parties

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MAY 23 1996

FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF SECRETARY

11 March 1996

Hon. Reed E. Hundt, Chairman
Federal Communications Commission
1919 M. St.
Washington DC 20554

**MM Docket 87-268**

Dear Mr. Chairman:

It has recently come to my attention that the Grand Alliance submitted Reply Comments in this docket on 22 January 1996. After carefully reviewing these comments, I have concluded that they contain a number of misstatements about interlace. On the basis of these misstatements, the Grand Alliance urges the Commission to permit an interlaced format for ATV, a step that I believe is very much contrary to the public interest.

Since the period for Reply Comments is over, and since I believe it is important to call attention to these misstatements, I herewith submit Informal Reply Comments addressed mainly to this issue. I request that these Informal Reply Comments be made a part of Docket 87-268.

It may well be asked why I have been unable to convert the members of the various ACATS committees to my views on the relative merits of progressive scan and interlace long ago. After all, this has been a consensus process where anyone who wished could attend any meeting and say what he liked.

The conclusion to which I came, reluctantly, was that most of the attendees at most of the many HDTV meetings that I attended have had, in effect, closed minds. This came about because they attended as employees of interested corporations. Their views were therefore dictated by their employer's current opinions, right or wrong, about what standards would be most in that company's interest. I rarely saw anyone openly change his mind in any way as a result of discussions at these meetings. On the other hand, Zenith and AT&T did adopt the 720x1280 progressive format first developed at MIT while I was the director of the Advanced Television Research Program.

An additional factor in this situation has been the inexperience of virtually all the technically trained committee members with the degree of interline flicker that occurs when the video signal has the full vertical resolution permitted by the number of scan lines. This is because normal TV cameras average together pairs of scan lines, reducing the vertical resolution (and, therefore, the spectrum efficiency) thus avoiding the flicker. Not one of the hundreds of engineers who saw the progressive-vs-interlaced side-by-side demonstration at MIT had ever seen this phenomenon before. (A similar demonstration was made by NIST at a meeting at Georgetown University 10-

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11 May 1995. Many of those most closely involved in the ACATS process attended the meeting, but very few bothered to see the demonstration.)

Computer engineers, on the other hand, use computer-generated video that is not vertically blurred and therefore causes intolerable flicker on interlaced displays. For this reason, virtually all computer monitors use progressive scan, and the computer industry is essentially unanimous in recommending the abandonment of interlace. This is all the more a sensible suggestion, since *I have shown in my Informal Comments that there is no advantage whatsoever is using interlace in the transmission format*. Under proper conditions, interlaced receivers might be used with progressive transmission for lower-cost lower-quality applications.

It is important to keep in mind that many viewpoints have changed radically during the period of the Inquiry in this docket. At the beginning, virtually everyone from the TV industry favored a receiver-compatible HDTV system and believed that it was impossible to transmit HDTV in 6 MHz. When contrary views were put forth by MIT, they were ridiculed, but, in the end, the Commission adopted the MIT views. In addition, hardly anyone believed that digital transmission was possible at the beginning of the process. In television, it seems that almost everyone can be wrong at the same time!

I would be pleased to provide any other information that the Commission desires.

Very truly yours,

William F. Schreiber

Cc:
Commr. James H. Quello
Commr. Andrew C. Barrett
Commr. Rachelle B. Chong
Commr. Susan Ness
Hon. Edward J. Markey
Mr. Richard K. Wiley
Mr. Larry Irving
Dr. Robert Pepper, FCC
Other interested parties

Before the Federal Communications Commission
Washington DC 20554

In the Matter of
Advanced Television Systems
and Their Impact upon the
Existing Television Broadcast Service

MM Docket 87-268
Fourth Further Notice of Proposed Rule Making and Third Notice of Inquiry
9 August 1995

# Informal Reply Comments of

William F. Schreiber
Senior Lecturer, Professor of Electrical Engineering, Emeritus
Research Laboratory of Electronics
Massachusetts Institute of Technology
Submitted 8 March 1996

*The opinions in these comments are those of the author only.
Since his retirement in 1990, the author has had no role in
directing MIT's Advanced Television Research Program.*

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## Executive Summary

These comments are directed at the Reply Comments of the Digital HDTV Grand Alliance, prepared by R. K. Graves Associates and submitted to the Commission on 22 January 1996. They are addressed specifically to the remarks about interlace and interoperability on pages 33-45. Those remarks include a number of technologically erroneous statements that are then used to support the contention that no harm can come from using an interlaced transmission format for ATV and that the interlaced format offers advantages to both the public and to the concerned manufacturers.

In this brief paper, it will be shown, by technical arguments only, that the use of interlaced transmission formats does not improve the vertical resolution for a given bandwidth and frame rate, does not require less bandwidth or channel capacity than progressive scan for the same resolution and frame rate, and is not necessary for permitting the manufacture of low-cost receivers. Thus there is no need to accept the artifacts and problems in transcoding caused by interlace or to give up the higher spectrum efficiency, the superior fine-detail rendition, and the better motion rendition provided by progressive scan.

*Based on these points, I propose that the transmission of interlaced formats be prohibited in both high-definition and standard-definition ATV broadcasting.* (Banning of interlaced receivers is not proposed.) I further propose, on the grounds of most efficient use of the over-the-air spectrum, that all ATV broadcasts (which would be in progressive format) utilize the full vertical definition that the number of scan lines makes possible. Since this would cause interline flicker on interlaced receivers, market forces will ensure that such receivers incorporate vertical low-pass filters to prevent flicker. If interlaced transmission is permitted, such filters should be required. At the very least, interlaced receivers without filters should be labelled to indicate that they will flicker with progressive transmission. Failure to adopt one or the other of these precautions will preclude any transition from interlaced to progressive scan transmission in the future. The interlaced format will then become the only format, and maximum efficiency in the use of spectrum will never be achieved.

## 1. Introduction

All commercial television systems to date have incorporated a system of interlace in which the odd lines of each TV frame are transmitted in one field and the even lines in the next. For example, the NTSC system, which sends 30 525-line frames every 1/30 second does so in two fields, each of 262.5 lines in 1/60 second. There are various ways to describe this process. One way is to think of it as doubling the large-area flicker rate. Another way is to say that the vertical resolution is doubled. Here we would be comparing a 30-fps 525-line interlaced picture with a 60-fps 262.5 line progressively scanned picture, both systems having the same bandwidth. The hope is that we can achieve the 525-line vertical resolution and the 60-fps flicker rate at the same time by using interlace.

Unfortunately, there is no free lunch. The interlaced picture shows more or less interline flicker, depending on the vertical resolution of the video information. The cause of this kind of flicker is the difference in brightness of vertically adjacent points that are in successive fields. In a picture devoid of detail, there is little interline flicker. (Even in blank areas, we may see some flicker when we look at the screen close up.) However, if there is a great deal of detail, flicker results, even as the screen is viewed from a distance. An extreme picture is one with alternate black and white lines, resulting in a black field followed by a white field. This would flicker at 30 cycles/second, and the flicker would be visible from across the room. Of course, ordinary pictures are not so full of detail -- they would flicker only in detailed areas.

All current camera tubes and solid-state camera chips automatically reduce the vertical resolution with the effect of getting rid of most of this flicker, so most TV engineers have never seen what would happen if full vertical resolution were present. Computer-generated video, particularly alphanumerics, does not have the same limitations as camera video, producing an unacceptable degree of flicker. As a result, computer displays have all used progressive scan for many years.

In all ATV systems, both SDTV and HDTV, the scanning formats of camera, transmission, and display are independent. This is different from today's TV, where all three formats are identical. Conversion between progressive (P) and interlaced (I) formats is possible. P to I is easier, since it only requires selecting every other line in every other field. I to P is somewhat more costly, since it requires generating a second set of scan lines, the best results requiring motion-compensated interpolation. If I receivers are used with P transmission, the conversion is cheap, especially since the ATV decoder requires the use of frame memories. I to P conversion would be required only at TV stations, where the converter cost would be negligible compared with the cost of the equipment required to enable any ATV transmission at all.

Because of the independence of camera, transmission, and display formats, each can be either P or I. The ATV system must be able to handle either P or I input material, since there is so much archival NTSC. Therefore, the encoder that produces the transmitted signal will surely be able to deal with either. Note that a progressive-scan signal with the same number of scan lines and frame rate as an interlaced signal (and therefore with twice the bandwidth) can be transmitted at the same data rate as the I signal after MPEG compression. (The reason for this is the greater redundancy and lesser aliasing of the P signal, as reported in a paper by Petajan of AT&T Bell

Laboratories.) *There is no data-rate penalty due to progressive transmission when coding is used.* Thus it makes a great deal of sense to use progressive transmission in all cases, and to permit both the signal source and the display to be either P or I. Of course, when all three are progressive, the highest quality is achieved.

*In summary, there is not a single compelling reason to use interlaced transmission formats in any new television system, and there are many reasons why this is a bad idea.*

Further details on these matters can be found in the Appendix.

2. Technologically Erroneous or Unsupported Statements in the Grand Alliance (GA) Reply Comments

2.1 The paragraph in the GA Reply Comments starting at the end of page 41 exemplifies the technologically faulty basis for the conclusions. Almost everything in this paragraph is incorrect.

> ''For example, denied the use of an interlaced format for HDTV, viewers of a sporting event would have to watch the program with either of two inadequacies: (1) at a lower frame rate, resulting in objectionable motion judder during camera pans and fast action; or (2) at a lower spatial resolution, resulting in a loss of clarity and sharpness.''

The writer seems to be comparing two uncoded analog formats, one progressive and the other interlaced, in which the former would have twice the bandwidth of the latter unless resolution or frame rate were reduced. Even for uncoded signals, I believe that quincunx scanning would give superior overall quality in the P format than in the I format, at equal bandwidth. However, in ATV, we are talking about coded digital systems, in which the data rate for the P and I formats are the same. In that case, the 720-line P format will have at least the same resolution as the 1080-line I format, as well as freedom from all interlace artifacts. It is not necessary to reduce either the frame rate or the spatial resolution in order to accommodate P scan, particularly in a coded system where progressive signals can be compressed to approximately twice the degree as interlaced signals.

> ''In the case of SDTV, denying the use of interlaced formats would either incur one of these two penalties or would reduce the number of programs that could simultaneously be carried over the channel.''

On the contrary, because of the higher compression ratio available to P signals, a larger number of programs can be simultaneously carried than if P signals are used for transmission. The 360-line P format, which, unfortunately, was rejected by the attendees at the ATSC T3/T6 conference of 14 March 1996, would do full justice to NTSC material. For high-end SDTV receivers using a 720-line P display, this would give quality substantially higher than that of NTSC and would permit more programs to be carried at the same time in a given channel.

> ''Interlaced scanning enhances spatial resolution at a modest compromise in temporal frame rate.''

Even in the uncoded analog form, interlaced scanning can enhance the spatial resolution only at the cost of unacceptable interline flicker, as previously explained. The compromise is not with frame rate, but with the interline flicker when it is attempted to get 525 lines vertical resolution with interlace in NTSC. This cannot be done with a conventional NTSC camera, which reduces vertical resolution by nearly 50% by averaging adjacent lines. In fact, the video information from a conventional NTSC camera is much like that from a camera that operates at 262.5 lines/frame, 60 fps, progressive scan.

> ''While interlaced scanning may not be optimum for computer text and graphics applications, it has a long track record of proven value and successful use in traditional television broadcasting and has many staunch defenders.''

This is the one statement in the paragraph that is correct. Interlace is not optimum for text and graphics. (Note that computer-generated graphics are widely used in NTSC at present, causing interline flicker unless ''antialiased,'' i.e., low-pass filtered.) NTSC with its I format has been a commercial success for more than 4 decades. One has to ask the question as to why we want to change it now. (See below.) If it is to be changed, then we certainly ought to replace it with a system that is as efficient in its use of spectrum as possible. As for the ''staunch defenders,'' most of them were pushing for an NTSC-compatible HDTV system a few years ago and virtually none foresaw digital transmission.

> ''In addition broadcasters must be concerned with the interoperability of an ATV transmission standard with currently available HDTV production equipment and with the installed base of NTSC production and studio equipment, virtually all of which employ interlaced scanning.''

In promulgating broadcasting standards for the United States, the Commission need not cater to the obvious desire of enthusiasts for the NHK system to facilitate the use of existing 1125-line equipment in ATV, either HDTV or SDTV. The MUSE transmission version of the 1125-line NHK system was tested at ATTC and found inferior to the systems now incorporated in the Grand Alliance format. If ATV broadcasting takes hold in the US, we can be sure that foreign companies will be quick to offer appropriate equipment. As for compatibility of the progressive ATV transmission standard with existing NTSC studio equipment, an I-to-P converter is required, the cost of which will be entirely negligible compared to the other costs of switching to digital transmission.

2.2 The second paragraph on page 42 relates to support in the industry for a standard with more than 1000 lines.

> ''There is a substantial body of broadcasters and others who believe that a high-definition format must have more than 1000 lines to be successful.''

While it is true that there is such a body of believers, their belief is incorrect. They are speaking about the number of lines in the picture rather than the actual vertical definition of the displayed image. Their mistaken belief is that the definition is proportional to the number of scan lines without regard for whether interlace is used or not. The resolution of the NHK 1125-line interlaced system, as shown on test patterns, was barely above 700 lines. The resolution of the GA 1080-line interlaced format will be less. On the other hand, the resolution of the 720-line progressive format from a good camera will be 720 lines. If one wanted super quality on high-end HDTV receivers, the 720-line signals could be presented on a 1440-line display.

An argument often made by the interlace proponents is that the 720-line progressive format does not have high enough vertical resolution. *However, the proposed 1080-line interlaced format will not have higher resolution; it may well have lower resolution.* Even with a perfect as-yet-not-invented camera, the interlaced format cannot have anywhere near 1000 lines vertical resolution without producing totally unacceptable flicker on the interlaced display.

That the interlace proponents do not understand this point is also shown by the change, after the first round of laboratory tests, from 960 lines (as used in the original ATRC system) to 1080 lines just to get over the magic number of 1000. (Remarkably, this change also makes the 1125-line equipment suitable for production in the GA system.) It is not clear exactly what resolution is needed to make HDTV a success, or even whether it is the vertical resolution that holds the key to success. In any event, the use of interlace has nothing to do with it; *interlace cannot raise the vertical resolution.*

> "...the proposed U.S.ATV standard...stresses progressive scan and square pixels."

It is true that most of the formats in the GA system are progressive. That does not amount to stressing progressive scan, since the presence of any interlaced format is likely to result in the death of all the P formats. The reason is that the first receivers will be interlaced, both to reduce costs and because that is what the manufacturers mistakenly prefer. (See below.) Full-definition P signals would cause unacceptable interline flicker on these first receivers, creating an intractable incompatibility problem. In that case, without the mandatory use of vertical low-pass filters (a step to which the GA Reply Comments strongly object) it is highly likely that progressive transmission will never be used.

2.3 The first full paragraph on page 43 includes the following:

> "...insistence on banning interlaced formats is unwarranted and self-serving."

In the foregoing, I have given ample technological justification to warrant the banning of interlaced transmission formats. The "self-serving" issue is nontechnological and is discussed below in Section 3.

2.4 The paragraph beginning at the bottom of page 43 discusses the desire of computer interests to use more than 60 frames/sec. This is now common in computer displays, as it considerably reduces eyestrain caused by extended close-up viewing of high-resolution graphics.

> "...increasing the transmission frame rate higher than 60 Hz would have to come at the expense of either reduced spatial resolution or increased compression artifacts..."

This is pure speculation. It may well be that a higher frame rate would reduce aliasing and increase redundancy to a degree that would permit the maintenance of spatial resolution without substantially worsening artifacts. The fact that P signals, with twice the analog bandwidth, can be coded to about the same data rate as I signals is quite suggestive. Under present conditions, it is unlikely that this point will be properly investigated. It is true, however, that good-quality conversion from 60 to 72 fps requires motion-compensated interpolation, which is not very simple.

2.5 The paragraph beginning on page 44 contains a number of nontechnically supported statements about interoperability that are discussed below.

3. Nontechnological Issues

A number of statements in the GA Reply Comments that are used to support the conclusions cannot be discussed on a purely technological basis. Even if no completely objective assessment of these points is possible, they are nevertheless important. What follows, therefore, represents my opinions based on my knowledge and study of the TV industry rather than conclusions that I have reached strictly on the basis of science in Section 2.

3.1 The second paragraph on page 33 expresses the belief that all the receivers to be manufactured will be able to cope with all the formats in the GA system, even without any mandate by the Commission.

One has to wonder why so many formats are included in the proposed standard. Without the slightest doubt, this will increase the cost of all ATV receivers, including the cheapest ones. It is no secret that the "Alliance" was imposed on the several proponents. I speculate that none of these reluctant partners was willing to give up his own format, so all were included. Of course, the GA cannot ensure that all manufacturers, even those in the Alliance, will follow this dictum. A manufacturer who is interested in keeping the sales price as low as possible and the profits as high as possible is highly likely to omit some formats. The first one to fall by the wayside, in my opinion, will be the 24-fps film format (actually an excellent format), followed by the 720-line P format, particularly if little or no broadcasting is done with either, as seems likely.

3.2 The last paragraph on page 36 objects to the required labelling of NTSC-only receivers to the (accurate) effect that such receivers will not be able to deal with digital broadcasts once the definite turn-off date for NTSC has been set. The protection of consumers by such labelling is widely accepted, from warnings about the suffocation danger of plastic bags and about the health hazards of cigarettes to listing the nutritional ingredients on most packaged food. As a citizen, I find it hard to justify withholding such vital information from consumers. Experience demonstrates that industry cannot be relied upon to inform the public in such cases, since the manufacturers who voluntarily do so are placed at an immediate disadvantage in the market as compared with those who do not. *Labelling requirements of this type are a protection, not only for consumers, but for the majority of manufacturers who want to do the right thing.*

3.3 The Motivation to Shift from NTSC to ATV

For all its defects, NTSC has been a very effective system. We are approaching 200 million receivers in the US, and TV has become the primary form of entertainment and information transmission. Many organizations have made and are continuing to make significant profits, and the public spends a great deal of time in front of the tube.

The original motivation to shift to ATV, as determined by the Commission, was to get the benefit of vastly improved picture and sound quality. Now that it appears that multiple standard-definition signals can be transmitted in each 6-MHz channel and that some of the NTSC taboo channels can be used, the main motivation is spectrum efficiency. This term relates to the amount of TV service, as measured by the number of program choices of a given technical quality available to each viewer, for a given amount of spectrum allocated to the service. Note that the number of programs that can be accommodated is inversely proportional to the required data rate of each.

Regardless of the degree to which the public cares about image quality, (everyone knows that the public cares mostly about program content) the Commission is making a trade-off between technical quality and amount of service when it sets a standard. *It therefore behooves the Commission to set a standard that gives the maximum technical image and sound quality for a given data rate.* In this respect, progressive scan is superior and should be selected. Interlaced transmission should not be permitted because it is likely to drive out progressive scan just as bad money drives out good money under Gresham's Law.

3.4 The "Self-Serving" Issue

It is puzzling why the GA Reply Comments raise this issue in the first paragraph on page 43 (even quoting Scripture!), since it is sure to generate skepticism among the readers. (Let the pot not call the kettle black, as folklore wisely suggests.) It should be recognized that nearly all the parties to the FCC proceedings are commercial establishments in the business of making money. The actual inventors all have their pride at stake, whether they hope to make money or not. In such circumstances, all parties can be expected to advocate Commission action that is in their own perceived interest. Under our form of government and our economic system, this is perfectly proper. It is for the Commission to make its decisions in the public interest. Parties to the proceedings are well advised to base their proposals as much as possible on verifiable facts.

Further on in this paragraph, the GA states that the market will choose progressive scan if it proves to be superior. The market will not have that choice. As I have pointed out in Section 2, above, the use of interlaced transmission, which surely would encourage the marketing of interlaced receivers, means that the full vertical resolution of progressive formats could never be used because it would cause unacceptable flicker on interlaced receivers that did not incorporate vertical low-pass filters. This means that the full spectrum efficiency of a new system could never be realized.

Finally, the GA upbraids the computer industry because of the incompatibility of the Mac and the

PC. This complaint comes with particularly poor grace from an industry that produced the Beta-VHS debacle that cost manufacturers, users, and the video-rental business a substantial monetary loss and inconvenience.

A more valid complaint that might have been made against the computer industry, which is larger and much more profitable than consumer electronics, is that it was unwilling to spend the money required to develop an ATV system that would meet its own interests as well as those of the consumer-electronics industry and the public. The Grand Alliance members did spend the money. It is my opinion, which I have voiced many times, that a much better system could have been developed if the computer industry had been willing to put its money where its mouth was. Regardless of these considerations, the decisions that the Commission must take at this time ought to be in the public interest, independent of the alleged moral superiority of any of the interested parties.

## 4. Conclusions

In this paper, I have tried to show, on technical grounds only, that interlaced transmission should not be permitted for either HDTV or SDTV. In addition, progressive transmissions should be required to be at full vertical resolution. If this were done, it would not be necessary to ban interlaced receivers.

The fundamental reason for my proposal is that interlaced transmission would make any subsequent transition to progressive transmission pointless. The higher vertical resolution and spectrum efficiency inherently available with progressive transmission could not be used since it would cause unacceptable interline flicker on the interlaced receivers that would certainly be sold for use with interlaced transmission. It is conceivable that interlaced receivers would not cause this trouble if vertical low-pass filters were mandated in such receivers, but it is unlikely that either the manufacturers or the Commission would accept such a requirement. ATV transmission in progressive format only with full vertical resolution would result in interlaced receivers being so equipped without any mandate from the Commission.

## 5. Appendix

The appendix comprises four short notes written between 1993 and the present. The first, "Excellent Television Engineers and Interlace" demonstrates that many highly experienced TV engineers have never seen the kind of interline flicker that occurs when the vertical definition of the video information is very high. The second, "A Few More Words About Interlace" is a recent piece in which I tried to debunk, in very simple terms, the most prevalent misconceptions about interlace. It was prepared for the ATSC T3/T6 meeting of 3/14/95. The third, "Some More Thoughts About Interlace," which I prepared after the NIST meeting at Georgetown University 10-11 May 1995, recounts some of the happenings at the meeting and also attempts to educate engineers on this subject. In addition, it recounts our experience at MIT showing a side-by-side demonstration of interlace vs progressive scan, in which *none* of the hundreds of experienced engineers who saw the demo had ever seen anything like it. The fourth, "Interlace," written in 1993, gives a brief but somewhat deeper account of the technical issues, in the simplest possible terms.

# Excellent Television Engineers and Interlace

A lot of excellent TV engineers work for Sony. During the project at MIT that was sponsored by Sony some years ago, we had a 512-line interlaced display connected to the frame store on our TV system. We usually got our pictures from a high-res laser scanner in which the adjacent scan lines were entirely independent. The interline flicker was spectacular - like what one sees on a VT-100 in the interlaced mode with computer-generated alphanumerics. It could be seen from across the room.

** Note: One does not have to resolve the scan lines to see the interline flicker. What is flickering is the object that differs on adjacent scan lines; said object can be quite large. For example, if the odd lines are black and the even lines are white (a legitimate TV picture, though rare) it flickers at 30 Hz and one can see the flicker at any distance. In practice, with high vertical resoultion at the source, interlaced displays flicker in all busy image areas, and this flicker can be seen even when one does not visually resolve the scan lines. It's only in blank areas that they don't flicker.**

What was most interesting was the reaction of the Sony people. They wanted to know what was wrong with the monitor!

This reaction was so striking that, when we had the right equipment, we set up a side-by-side demo of an interlaced and progressive monitor with the same still picture. It was the back of a dollar bill, with four different kinds of vertical filtering. (There are some filters that somewhat reduce the flicker without as much loss of vertical resoultion as normal.) We showed this to hundreds of visitors. No one had ever seen this phenomenon before, and this includes executives and working guys from ABC, NBC, CBS, Harris, Tektronix, PBS, Ampex, Kodak, Zenith, and all our other sponsors.

The basic reason for this is that in normal NTSC (and PAL and SECAM), the cameras erase the entire screen every field, and thus have a true vertical resolution only about half what one would think. It is this reduced resolution that avoids the flicker. If the screen doesn't flicker, then progressive scan doesn't help.

People normally think of interlace as a way to double the large-area flicker rate with a given bandwidth. Another way is to use it to double the vertical resoultion as compared with a progressive system with half the lines. This is discussed in E.F. Brown, BSTJ 46, 1, 199-232, 1967. He found that the improvement depended on luminance and was only about 10% at normal CRT luma. INTERLACE DOESN'T WORK; WE ONLY THINK IT DOES.

# A Few More Words About Interlace

William F. Schreiber
36-545 MIT, Cambridge, Mass. 02139

Although there are many other important considerations in choosing formats for "standard" definition digital TV transmission, in this short note, I shall deal only with interlace. There is no more troubling issue in TV standards-setting, and apparently none in which entrenched positions are more difficult to move. Some have dismissed the entire controversy as religious in nature, but I think this misses the point. In TV issues, it is possible for most of those involved to be wrong at the same time. We have only to look at what has happened in the period of the FCC Inquiry since 1987. Most participants were wrong on the simulcast-vs-compatible-system issue, the digital-vs-analog issue, and on the question of whether HDTV could be transmitted in the 6-MHz analog channel. Many of these very same people are among those most adamant that interlace must be a part of any new TV standard. Here are some of the points that have been raised together with a brief discussion of each.

**Interlace doubles the vertical resolution for a given bandwidth and frame rate.**
This is the most important technical issue. In fact, with interlace (I), the hoped-for factor of two improvement in vertical resolution must be reduced by nearly 50% (depending on screen brightness) to avoid totally unacceptable interline flicker. A study by Bell Laboratories in 1967 showed that, at normal brightness, only a 10% increase in vertical resolution could be obtained with acceptable interline flicker. Against this marginal improvement, we must balance the many other artifacts caused by interlace, including the disappearance of half the scan lines with vertical motion of an integral number of lines per frame. Progressive scan (P) has none of these artifacts.

**P scan requires more bandwidth or channel capacity than I for the same resolution.**
This is the next most important technical issue and one that we have fought over for a long time. Even at the uncoded analog video-signal level, right out of the camera, the same bandwidth, and therefore the same SNR, can be had by using "quincunx" sampling, which involves sampling alternate points on alternate lines. The progressive scan pictures thus sampled would have lower diagonal and higher vertical resolution, and they would be completely free of the artifacts long associated with interlace. At the digitally coded transmission level, Petajan at AT&T Bell Labs has demonstrated that the coded P signal, with full diagonal resolution and *twice* the analog bandwidth, requires the *same* digital data rate as the coded I signal. Of course, it is also free of all of the I artifacts.

**We have to have interlace so that we can have cheaper receivers.**
If transmission is progressive scan, receivers can still be interlaced, and therefore slightly cheaper. It is very easy to convert from P to I by omitting every other line in every other field. In the case in which (as I believe should be mandated), the P transmission has full vertical resolution, a vertical filter is required to prevent interline flicker on the I receiver. The cost should be no more than that of a comb filter. The filter could be switched in under control of a header in the transmission. *If no such filters are required in interlaced SDTV receivers, then P transmission with full vertical resolution will not be possible because it will cause flicker on these receivers.*

**Progressive scan raises costs for broadcasters.**
The cost of the I-to-P converter that is required when the source material is in I form will be a negligible part of the total cost of shifting to multiplex digital transmission. If broadcasters become convinced that there is money to be made in SDTV digital transmission, they will make the investment. If they are not convinced, the small cost of the converter will not enter into their decision.

**No one knows how to make progressive-scan cameras with high SNR.**
Since excellent cameras have been demonstrated in Japan for the 525-line P format, one would think that this canard would have disappeared. There was never any question at all about the SNR of P cameras except at the HDTV level.

**Many programs that will be used for SDTV transmission exist in NTSC format.**
Although it may seem odd to go from I to P at the TV transmitter and then go from P to I at the receiver, the total cost and quality loss that will be encountered will be small. NTSC video always has rather low vertical resolution. Even 360-line P transmission is sufficient to do justice to an NTSC signal. If we fail to think about the future, we shall be stuck for decades with a digital system that retains many of the inherent analog NTSC limitations and defects. When will there be a better chance to change to a superior system than now?

**Transcoding**
A key issue is the cost and quality of transcoding, which must be widely used in any TV broadcasting system. Format conversion is so much a part of TV -- todays's and tomorrow's -- that it must be considered in system design. No one can disagree with the statement that transcoding is easier and more successful from a P format than from an I format. The basic reason is that, if the frame rate is the same, no temporal interpolation is required. Note that, even after decades of experience, NTSC<->PAL conversion is far from perfect.

**Conclusion**
*There is not a single compelling reason to use interlace in any new TV system.* Interlace does not conserve bandwidth, improve SNR, or provide any substantial economy. On the contrary, it will retain all the interlace artifacts now present in NTSC and prevent high-quality transcoding. That means, of course, that the spectrum allocated to television broadcasting will not be used with maximum possible efficiency.

If we permit interlaced transmission, progressive transmission will be driven out just as bad money drives out good money under Gresham's Law, and we shall forever have poorer quality for the same data rate than we would have had with progressive. We shall not have another opportunity to shift to a substantially better system for many decades than we have right now. Now is the time to make this change.

Some More Thoughts About Interlace

One would have thought that everything that might be said about this subject had already been said. However, after the Advanced Digital Video conference organized by NIST in Washington May 10-11, it seems that we are not quite finished.

The Grand Alliance proposes to transmit a number of different formats including 1080 (active) lines x 1920 interlaced and 720 x 1280 progressive scan. (proscan) Film will be 1080 lines progressive at 24 fps. It seems that the main reason for including all these formats is that no GA participant was willing to give up his favorite format. This admittedly raises the receiver cost. The GA members have agreed to make all receivers accept all formats. Of course, they do not have the power to do enforce this, and the FCC is most unlikely to do any kind of receiver regulation. Whether the FCC will even prove willing to mandate the special film format remains to be seen.

Another reason that appeared in news reports was that there was strong sentiment for having more than 1000 lines, thus the change from 960 interlaced (which was the ATRC format) to 1080. Everyone pays lip service to the idea that proscan is better and so there is a migration plan to go to 1080 proscan eventually. Of course, 1080 lines interlaced will not give higher vertical resolution than 720 progressive. The attempt to do so will make the interlaced receiver have so much interline flicker as to be unwatchable. There apparently still are some who don't believe this, but it is nevertheless true and easily demonstrated.

The failure to understand the vertical resolution implications of interlace extends to the testing process itself. The first round of testing used a BTS 720-line proscan camera that was not very good. Later, a clever scan converter was developed that made improved 720-line proscan material from 1125/60 interlaced. Since the output of the converter has to be worse that its input, and has to have a vertical resolution substantially below that of the input, the proscan systems were put at an immediate disadvantage that will remain until a good 720-line proscan camara appears. This is because the proscan systems themselves undoubtedly have a higher vertical resolution that the video from the 1125/60 interlaced camera.) This extra resolution is going to waste in the tests. Note that the two proscan systems did much better than the interlaced systems for computer-generated material.

I find that I have developed a certain amount of paranoia after spending 10 years on HDTV. Readers may think that this is the reason why I am suspicious of the choice, since 1080 active lines makes the 1125/60 system the production standard once again. Some of the same people who tried so hard to make 1125/60 the international production and program-interchange standard are still at it. Another item along these lines is that both Ikegami and Matsushita had offered to build 720-line proscan cameras for the US system proponents for about $1 million, but withdrew their offers. It is rumoured that they did so under pressure, both Japanese and American. At the NIST meeting, Matsushita demonstrated an excellent 525-line proscan camera. If a 525-line camera can be made, I would be willing to bet that a 720-line camera can also be made.

My Assumptions

I regard the following as facts, but since everyone does not agree, I shall call them assumptions. On an interlaced display, if there is a substantial difference between adjacent lines in a frame (which lines, of course, are in different fields and displaced in time by 1/60 sec) interline flicker at 30 Hz will appear. If the adjacent lines are identical, they must be resolved by the eye to see the flicker. If adjacent lines are different, the larger the differing area, the greater the distance at which the interline flicker is visible. An extreme case is one in which the odd lines are white and the even lines are black — a legitimate although very unusual NTSC picture. This flickers at 30 Hz and is visible even from a distance at which the entire display seems to be a point source.

The computer industry has abandoned interlace because of the severe flicker caused by display of computer-generated alphnumerics and graphics. At recent SMPTE conventions, there have been about as many computer monitors on the floor as TV displays. One would have to be blind not to notice that the TVs were shimmering away while the computer displays were nice and quiet.

For many years in my MIT laboratory, we had a 512-line interlaced display operating from a frame store connected to our computer. Many of the pictures in the system were from a high-resolution laser scanner, and flickered wildly in detailed areas. Many highly experienced TV professionals saw this and usually thought that the monitor was faulty. Later we made a side-by-side comparison of interlace and proscan of the same image — the back of a dollar bill — and showed it to executive and engineering personnel from ABC, CBS, NBC, Tektronix, Ampex, and others. None had even seen it before and were generally astonished. The reason for this is that video from interlaced cameras is inherently of low vertical resolution. In tube cameras, it is because the entire target is discharged in 1/60 sec. (If it were not, that would lead to other problems, such as serrated vertical edges of horizontally moving objects.) CCD cameras usually discharge two lines at a time when in interlace mode.

As a result of this situation, most TV professionals have never seen the very large interline flicker that invariably results when full vertical resolution is present in the video. They are therefore improperly calibrated at to what picture quality to expect with a certain number of lines, and generally do not realize that the lack of flicker means that the resolution must be much less than the number of lines per frame. I believe that this accounts for the mistaken notion that 1080 lines interlaced has a higher vertical resolution than 720 lines proscan.

One rarely gets to see resolution charts during HDTV demos, but I have seen some. It is worth noting that current 1125/60 cameras have a *limiting* vertical resolution of not much more than 700 lines. In addition, interline flicker is never seen in demos of the 1125/60 interlaced system, whereas some interline flicker is seen in NTSC. I conclude, therefore, that the vertical resolution of the HDTV cameras is lower, with respect to 1125, than that of 525-line cameras is to 525. Another piece of evidence comes from a demo at the old CBS laboratories in Stamford, Conn. They had an 1125/60 system that they had modified so that it could be operated at 562 lines progressive. When switched to proscan, the resolution did not decline noticeably. All that happened was that the line structure became more visible.

A final incident that can be added to the mountain of evidence that already exists comes from a tour of European TV laboratories that I made in 1985. All of them were showing 625-line video (PAL) upconverted to 625-line proscan or 1250 line interlace. My comment in every case was that the upconverted images, while they looked quite nice, were softer than the originals. We had the same result in our own audience testing facility when the viewers unexpectedly preferred NTSC interlaced over the images on a Hitachi upconverter. The moral of the story is this: If the picture flickers on the interlaced display, it can be improved by upconversion, but not otherwise. If the interlaced picture does not flicker, then upconversion cannot make much of an improvement, and the need for interpolation is likely to reduce the sharpness.

## The Consequences of Permitting an Interlaced Format

If the FCC approves the use of the 1080-line interlaced format as one of the many formats to be transmitted when HDTV broadcasting starts up, then I predict that we shall not have proscan for the forseeable future. The 1080-line format will become the dominant format and eventually the only one used. It is conceivable that this eventuality might be forstalled if the FCC were willing to establish some receiver standards, but I think that it is most unlikely to do so. If the FCC showed a desire to go that route, then I believe that Congress would give them the authority to do so if they felt that they did not already have such authority.

The horizontal deflection circuitry of a TV receiver is costly relative to other circuitry, since higher power is required. The power and cost go up as the scan rate increases. Generally, therefore, interlaced receivers are cheaper to manufacture and will have lower prices. Furthermore, to prevent interline flicker on these sets, the video will have to be limited in vertical resolution. This will happen automatically with video from interlaced cameras, but will have to be done deliberately with telecine- and computer-generated material, of which we can expect more and more as time goes by.

Presumably, receivers that accept more than one format will do so by scan converting to their display format, which is likely to be fixed. Scan conversion is probably cheaper than using a multisync monitor. The 1080-line interlaced receiver (the cheapest) will therefore waste all the extra vertical resolution provided by 1080-line proscan for movies and 720-line proscan that may be used by some broadcasters. That, however is not the worst result. Lower performance for a lower price is to be expected. The worst result is that the attempt to introduce even higher resolution such as 1080 proscan, will find a population of cheaper receivers that will flicker markedly with such material. If the 1080 proscan has to be filtered down so as not to flicker on 1080 interlaced receivers, then there is no point at all in making the transition, and we shall be stuck with interlace forever. In other words, we shall have introduced an unsolvable reverse-compatibility problem by permitting any interlaced broadcasting. This would defeat the FCC's expressed desire for nondisruptive improvability over time.

## The Interoperability Argument

Progressive scan and square pixels are the minimum demands of the non-TV imaging interests whose lobbying pushed the FCC into making interoperability a subject of study by the Advisory

Committee on Advanced Television. (ACATS) The focus of this study has, unfortunately, gotten diverted into the question of choosing a packet transmission format suitable for use on general-purpose digital communication networks. Of course, if there are going to be a number of formats transmitted, then the signals must identify themselves, and there is nothing wrong with headers and descriptors to serve that purpose. However, the main difficulties that will be encountered in transcoding from the broadcast format to something suitable for a computer display relate much more to the fundamental scanning parameters rather than to a good packet structure. Even the question as to whether a transmission is digital or analog is much less important than whether the formats are progressive or interlaced.

The main reason for the difficulty in transcoding between NTSC and PAL, for example, is that a high degree of temporal aliasing is almost always present. (For the kind of motion routinely seen in TV, even hundreds of frames/sec would not be enough to eliminate temporal aliasing without introducing an unacceptable degree of blurring.) If not for this, the sampling theorem and some appropriate low-pass filters would suffice. As it is, with aliasing present, any temporal filtering is likely to produce defects such as multiple images or excessive blurring.

In principle, it is possible to design a coding system that is independent of the sampling grid and that could be displayed on any grid at all with a quality that depended only on the resolution offered by the grid. Such is the case with contour coding of typographical characters as in the Postscript page-description language. However, TV coding has not gone that route, and I suspect that hardly anybody wants to discard MPEG at this point and go back to the drawing board. With progressive scan, temporal filtering is not needed for most transcoding. With respect to film, we have all gotten used to the defects of 3/2 pulldown and are prepared to live with it until motion-compensated interpolation becomes practical.

What to Do?

At the recent NIST meeting, I suggested that it might be possible to avoid the reverse compatibility problem presented by a population of interlaced receivers by labelling receivers as to scan format and by requiring all transmissions, in whatever format, to be of full vertical resolution. This would minimize direct regulation of receivers, but, indirectly, would require interlaced receivers to incorporate vertical low-pass filters. I thought this would have been a reasonable compromise, since it still permits broadcasters to use the 1080-line interlaced format. The proposal met with no positive response. I have concluded, therefore, that we should simply forbid broadcasting of interlaced HDTV images. This type of decision is certainly within the FCC's standard-setting prerogatives, and there is ample precedent for making this kind of rule. I intend to push for this solution in whatever forums are open to me, and I urge others to do the same.

The interlace/progressive argument would be much clearer if there were suitable demos that showed that proscan gave better results at the same data rate as interlace. There are many partial demos, including a paper from Eric Petajan of Bell Laboratories distributed at the NIST meeting. This paper showed that when an original proscan sequence was converted to interlace by discarding every other line in every other frame, and that when both versions were coded to the *same* data rate, the proscan sequence (which had twice the uncoded data rate) looked *better*. This indicates that there is *no* penalty in transmission rate for using proscan.

I still cannot understand why companies that have a financial interest in the outcome are not willing to spend the money required to do more along this line.

William F. Schreiber 26 May 1994

## Interlace

Aside from the compatibility question, there is no more troublesome aspect of TV system design than whether to use interlace or progressive scanning. Not only is there widespread misunderstanding of the technical aspects of interlace, even among TV professionals, there are political and economic considerations that have further confused the situation.

Interlace is widely misunderstood, even by TV professionals. The computer industry has abandoned it because of intolerable interline flicker on computer monitors. The TV industry is much less bothered by this because TV cameras characteristically have low vertical resolution. Discussion on the issue is confounded in part because most TV personnel believe that interlace is an effective way to halve the bandwidth requirement. Another complicating factor is the wish of companies that make 1125/60 equipment to have this equipment used as is for HDTV production.

### *The ATTC Test Results*

After the ATTC tests, there was a heated discussion, partly by e-mail, about the desirability of using interlace in the new ATV system. A meeting on this subject was held in Chatham, Mass. in May, 1993. The pro-interlace group includes personnel of the Sarnoff Laboratory, Sony, and NHK as well as Rennville McCann, consultant to CBS. The anti-interlace group includes virtually all representatives of computer companies, who are influenced primarily by interoperability considerations. It is conceded by everyone that progressive scan is superior from the standpoint of interoperability, but the interlace advocates think that that is not their problem and, since progressive scan takes twice the bandwidth, that it is not practical.

C. K. P. Clarke of the BBC Research Department has done a study indicating that progressive scanning has an important role to play in future systems. [BBC RD 1987/18] A very important conclusion he reached was that the primary advantage of interlace was a reduction in the visibility of line structure (he compared 625 lines interlaced with 312.5 lines progressive) but that both systems could render about the same spatiotemporal spectrum of video information.

Unfortunately, nearly everyone involved in the discussion is an employee of a company with a vested interest in the outcome. For example, the Japanese evidently still hope that 1125/60 will be the *de facto* production standard, so that their existing lines of equipment will dominate the professional market from the start. The computer companies' interests are likewise obvious. They are interested mainly in interoperability.

In the ATTC tests, the two interlaced systems had slightly higher subjective quality than the two progressive systems, except on a computer-generated sequence in which the scores were reversed. The progressive proponents claim that the trouble was that the progressive camera that they used was inferior to the Sony interlaced camera, which may well be true.

Involving as it does perceptual considerations, camera and display technology (now and in the future), possible effects on compression ratio, and in the absence of definitive tests, it is very difficult to present an analysis that is both convincing and unbiased. I shall try.

*How Interlace Works*

The primary advantages usually associated with interlace (Clarke's conclusions, above, are quite novel) can be thought of from two different points of view. For a given bandwidth, interlace, if it works perfectly, either doubles the vertical resolution or it doubles the large-area flicker rate, depending on the scan parameters. In fact, in neither of these effects does it work very well except at very low display brightness. Long ago, Brown [E. F. Brown, Bell System Tech. J. 46,1, 199-232, 1967] found that these hoped-for factors of 2 depended on brightness and were only about 1.1 at typical display brightness. In addition, interlaced displays are subject to interline flicker and produce quite noticeable aliasing in the presence of movement. Why then has interlace been used for so long? Why has it been abandoned for computer displays?

Interline flicker is not very troublesome in today's TV primarily because interlaced cameras, both tube and solid state, have very poor vertical resolution due to the fact that the integration time per sample is one field time and not one frame time.[1] Thus the light input to two adjacent scan lines in the camera is averaged, causing vertical blur. If the video information actually has full vertical resolution as limited only by the number of lines/frame, then interline flicker occurs in all detailed areas of the image. The scan lines do not have to be resolved either by the eye or the CRT for this flicker to be visible. As long as the *horizontal* extent of the detail on adjacent lines is both visible and different, interline flicker occurs at the frame rate. Typical pictures from a laser scanner, for example, flicker unacceptably when displayed on an interlaced monitor. An extreme example is a picture with alternate black and white lines. *The vast majority of TV people have never seen this effect.* During a period when my MIT laboratory had a Sony contract, I showed this to dozens of Sony engineers, none of whom had seen the effect previously. (They genrally thought that there was something wrong with the monitor.) We later had a demonstration of the effect using a laser-scanned image of a dollar bill, displayed both interlaced and progressive. We showed it to hundreds of visitors, and it was a surprise to every one, without exception.

Another flaw in much of the analysis is the assumption that the vertical resolution of a camera depends primarily on the beam diameter and is independent of the scan format. [T. G. Schut, "Resolution Measurements in Camera Tubes," J.SMPTE, 92, 12, 1270-1293, 1983] The equilibrium discharge of a camera target is a nonlinear process; the effective spot size and shape depend on the local image intensity and the corresponding amount of charge. Except at very high brightness, as the beam moves down the camera target, discharge is primarily effected by the leading and lower edges of the beam. A given camera typically will have substantially higher vertical resolution with progressive scanning than it has with interlace. The limiting vertical frequency response, (which can, of course, be less for inferior tubes) for images of full dynamic range, is simply the number of scan lines per *field*. This reduces the resolution when interlace is used, and this is why we see little interline flicker in NTSC and PAL.

A point often made by interlace enthusiasts is that progressive displays are only better because they have twice the bandwidth. They also state that a progressive camera with the same

[1] This "defect" of interlaced cameras actually is essential to make the pictures at all acceptable. If the integration time at each sample point were one full frame rather than one field, then objects in horizontal motion would show serrated vertical edges.

resolution as an interlaced camera is much less sensitive because it has twice the bandwidth and therefore more noise. By resolution, they mean the number of samples/frame, the progressive camera having twice the bandwidth.

Of course, cameras must be compared at the same bandwidth. I believe that the proper comparison would be between two cameras with the same number of scan lines/frame and the same vertical scan frequency. The progressive camera would use quincunx sampling preceded by a diamond-shaped spatial filter, so that both signals would have the same sample rate and bandwidth. (The interlaced signal could be derived from the same camera if alternate lines on alternate fields were discarded after processing by a diamond-shaped spatiotemporal filter. This would reduce the vertical-temporal aliasing commonly seen today.) The sensitivities would now be much closer. Recall that the fundamental limitation on camera sensitivity is the number of photons per picture element. Two systems that use different scan patterns but have the same picture-element rate have the same limiting sensitivity.

I think it reasonable to assume that, in the future, cameras will improve with respect to vertical resolution. There certainly will be much more use of computer-generated imagery, which does not have the limitations caused by camera physics. In view of the better interoperability of progressively scanned systems and because of the absence of the interlace artifacts referred to above, I think progressive scan is the clear choice for future systems.

wfs July 1993